Chapter 8

Aggregate Timber Supply

From the Forest to the Market

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Timber supply modeling is a means of formalizing the production behavior of heterogeneous landowners managing a wide variety of forest types and vintages within a region. The critical challenge of timber supply modeling is constructing theoretically valid and empirically practical aggregate descriptions of harvest behavior. Understanding timber supply is essential for assessing tradeoffs between forest production and the environment, for forecasting timber market activity and timber prices, and for evaluating the level and distribution of costs and benefits of forest policies. It follows that timber supply modeling is an essential interface between forest production economics and policy and decision making. This chapter examines timber supply modeling, focusing especially on issues regarding aggregation of timber stocks (some of this chapter is based on Wear and Parks 1994). A section on general theory is followed by a discussion of various contemporary modeling approaches. The explicit aggregation of forest capital and description of capital structure in the analysis of timber supply remain as core research issues. We conclude with an empirical example that explores these topics.

1. THEORY

Timber supply models summarize the production behavior of forest managers in a market setting. Their conceptual foundation is the biological/physical production possibilities of timber growing and inventory adjustment, as well as information on the objectives of forest landowners.

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When sector-level timber supplies are to be examined, heterogeneous forest land and owners with heterogeneous objectives must be aggregated.

1.1 Timber Production Function

Underlying any economic study of production is a production function that translates inputs into outputs (see chapter 5). For timber supply, the inputs should include the age of the forest, (a) the level of forest management effort (E), and the quality of the land (q) (Binkley 1987). Merchantable timber volume per unit area (V) is given by the yield function:

$$V = v(a, E; q) \qquad 8.1$$

The marginal physical product of age and management effort is positive and decreasing in the relevant ranges of age and effort. Provided that the forest manager's objective function and discount rate can be specified, then the forest yield function can be used to define if and when a forest stand would be harvested. For example, consider a manager who faces prices (p) for timber and (w) for management effort (in this case, effort used to reforest the land after harvest). When the land is maintained indefinitely in forest use, the manager will maximize profit by selecting harvest ages (u) and levels of effort (E) to optimize:

$$\pi^F = \max\{a, E\}\sum_{j=0}^{\infty}\{pv(a, E; q)e^{-ra} - wE\}e^{-raj} \qquad 8.2$$

The optimum profit obtained, π^F, is the present net value for an infinite sequence of identical harvest ages. This formulation provides a valuation for forest land of quality (q) when there are no trees present at the beginning of the manager's planning horizon. The manager's problem can easily be modified to account for standing timber inventories; however, when profit from timber enterprise is the only argument in the objective function (cf. Hartman 1976), the solution for optimum age (a*) is unaffected by the manager's starting inventory of timber. With this definition of profit, the manager recognizes that there is an opportunity cost to holding old trees rather than faster-growing young trees, and that this opportunity cost influences the harvest timing decision.

As long as the manager's optimum timber profits are positive and greater than the value of land in alternative uses, then the manager's solution to 8.2 will identify profit-maximizing harvest dates, harvest volumes, and levels of regeneration effort. The optimum harvest age is obtained where the marginal benefits from delaying the harvest are just equal to the marginal opportunity costs of the delay (see chapter 4).

When forest management decisions are guided by utility rather than profit maximization (i.e., objectives include more than marketable timber products), the forest management problem may be more complex than the problem described by equation 8.2. For example, nonpriced amenity services in the manager's objective function, or forest-level constraints, may bind on local decisions (see Pattanayak et al. 2002 for a recent summary). However, even when these questions are addressed in the manager's problem, similar decision rules result (i.e., harvest occurs where marginal benefits and costs of delaying harvest are balanced). For subsequent discussion here, we posit that a decision rule exists which defines the economically optimal harvest age for each forest owner and quality class. If we define the manager's current expectation of future market prices as p^e, the manager's optimum harvest age under these expectations, (a^*), is given by

$$a^*\left(p, p^e; q\right) = a : MBD^e\left(a, E; q\right) = MOC^e\left(a, E; q\right) \qquad 8.3$$

The optimum harvest age depends on current market signals (p) and market expectations (p^e). This optimum age is not necessarily the same as that given by the timber-only solution and may vary over time as price expectations are revised. Equation 8.3 is a long-run solution when all elements of p^e are equal to p.

1.2 Aggregate Supply

The core challenge of modeling and evaluating timber supply is constructing some meaningful aggregation of the individual stand harvest decision to define the relationship between aggregate harvest quantity and price. Neoclassical models of supply build on the assumption of a typical producer and, accordingly, develop from a prototypic production function such as equation 8.1. However, timber inventories are heterogeneous (they can be viewed as rather complex capital stocks), and timber is produced from forests allocated to a variety of uses, most of which yield joint products. This indicates that each forest type has a different production function or, more conveniently, that some quality variable shifts a common production function. Modeling timber supply is therefore a nontrivial undertaking. One way to develop an aggregate supply model is to start with the aggregation of individual harvest choices.

$$S^{SR} = \sum_{i=1}^{I} \sum_{j=1}^{J} A_{i,j} \{v(a,E;q)\} * H_{i,j} = g(p,p^e)$$
$$\text{where } H_{i,j} = \begin{bmatrix} 1 & \text{if harvest occurs at } p,p^e \\ 0 & \text{otherwise} \end{bmatrix} \qquad 8.4$$

where $A_{i,j}$ is the area of forest in age class i and quality class j; $H_{i,j}$ is a binary variable that describes the harvest decision; and, because H depends on the age of the stand as described above, the aggregate function (g) is conditional on the age and quality distribution of the forest. Supply is conditioned on the current distribution of quality and age classes and implies that a common decision model describes the behavior of all landowners.

Generalizing supply to address variable forest conditions requires including some description of forest inventory as an argument in the supply function. One way to consider the influence of forest inventory in g is simply to include a variable that measures total inventory quantity (I).

$$I = \sum_{i=1}^{I} \sum_{j=1}^{J} \{v(a,E;q)\} \quad \text{and}$$
$$S^{SR} = g(p,p^e,I) \qquad 8.5$$

This approach is common in applied analysis but provides no logical link to the mechanism of the harvest decision defined by equation 8.2—i.e., the aggregate quantity of inventory says nothing about the age and quality distribution of inventory which influences the harvest choices that define supply. To illustrate, equation 8.5 implies that a gain in the sapling volume of the forest would have the same impact on aggregate output as would a gain in sawtimber volume. To address this shortcoming, this simplified model might be expanded to include arguments for separate vintages of timber that are the components of I.

Another way to motivate the development of an aggregate timber supply is to specify an aggregate production or transformation function. In this case, the focus shifts from the stand as the fundamental unit of production to the forest as a whole. The intertemporal aggregate transformation function is defined as:

$$T(S, I_{t-1}, I_t, X, Y) = 0 \qquad 8.6$$

where S is timber output; I_{t-1} and I_t are vectors of inventory volumes for timber of various qualities at the beginning and the end of the time step; X is a vector of other inputs; and Y is a vector of other outputs. This approach accommodates the view of timber as both input (starting growing stock) and as output (harvested timber and inventory at the end of the period) and accommodates the joint production nature of forest production. Collapsing S and I into the vectors Xand Y provides a compact representation:

$$T(X, Y) = 0 \tag{8.7}$$

If the production model in 8.7 has certain desirable attributes related to its curvature and the separability of inputs and outputs, then a dual function can be used to summarize the behavior of profit-maximizing entities operating with the technology described by the production model (see Chambers 1988). This dual function is generally either a cost function or profit function but could be a revenue function, depending on the degree of flexibility allowed by the production technology. If, for example, we assume that output prices or quantities are fixed for the time step analyzed, then the producer can only minimize cost so that the cost function is the appropriate dual function. If both output and input quantities can be fully adjusted to optimal levels, then a profit function is the appropriate dual function.

Consider the profit function:

$$\pi^{LR} = h(p, w) = 0 \tag{8.8}$$

where p is a vector of output prices corresponding to elements of the output vector Y, and w is a vector of input prices corresponding to elements of the input vector X. Because all inputs and outputs are fully variable-that is, they can be adjusted to their optimal levels without adjustment costs-a long-run profit function is defined (indicated by the superscript LR). If, on the other hand, some of the inputs cannot be optimally adjusted, then a constrained or short-run profit function would apply. In such a case, the observed profit is a function of output prices, the prices of fully variable inputs, and the level of those inputs that cannot be fully adjusted-generally labelled quasi-fixed inputs and included as a separate vector Z here. The inventory of timber is generally quasi-fixed in the case of forest production because the starting age/species distribution heavily constrains what the forest composition can be at the end of the period.

$$\pi^{SR} = h(p, w; Z) \tag{8.9}$$

Output supply can be directly derived from the profit function by taking the partial derivative of profit with respect to price (Hotelling's lemma).

$$\frac{\partial \pi^{SR}}{\partial p_i} = S_i = g_i(p, w; Z) \qquad 8.10$$

Building an aggregate supply model using this approach requires (1) defining the full complement of inputs and outputs relevant to the transformation function (equation 8.7), (2) defining meaningful input and output aggregates for empirical work, and (3) determining whether inputs/outputs are fully variable over the time step considered (so price enters the function) or quasi-fixed (so quantity enters the function). In addition, in forestry we face concerns regarding the aggregation of different owner groups. Typically, separate functions are defined for forest industry and nonindustrial private forest owners.

Developing supply models from the summation of individual choice models and from an aggregate production model leads to the same conceptual endpoint. Supply should be a function of price and of input costs and is conditioned on the state of the forest inventory. The core issues in empirical work are (1) determining a meaningful description of forest inventory and (2) addressing dissimilar forest owners.

2. MODELING APPROACHES

Aggregate timber supply models have been developed using a variety of approaches which develop either from aggregation of individual or representative forest owner models or from aggregate production models. In general, these can be grouped into normative and positive approaches, but it is important to emphasize that timber market modeling, especially when applied to the long run, in application is rooted as much in data management as it is in theoretical modeling. As a result, timber supply models are often developed as hybrids of these two approaches.

2.1 Normative Approaches

One approach to modeling timber supply is to apply stand-level management optimization models (equations 8.2 and 8.3) for all forest types within the region being studied. The approach requires assumptions regarding market structure (e.g., perfect competition), a forest inventory (i.e., a definition of forest land by quality classes), and some definition of the biological production functions (e.g., empirical growth and yield tables). Given this information, the analyst can calculate the optimal rotation and derive the implied annual contribution of each forest type to total production.

Supply relationships can then be examined by mechanistically simulating the production response to changes in timber prices.

2.1.1 Static Engineering Models

The original applications of normative models to timber supply defined the optimal rotation for each quality class of forests and then summed up the average annual harvest implied for each forest class to define supply (e.g., Vaux 1954). These are long-run models because they do not explicitly address the age structure of forest capital (they assume a long-run adjustment to an optimal age distribution). They address *maximum potential* timber output, in that they provide no practical mechanism for describing the actual behavior of timberland owners. These models provide an extremely rich supply specification and, as shown by Hyde (1980) and Jackson (1980), can provide tractable comparative statics for forest sector policies related, for example, to public land management and timber taxes. An application of engineering models to the supply effects of public timber management is developed in chapter 12.

2.1.2 Intertemporal Optimization

Another class of engineering models directly simulates short-run harvest and inventory adjustments by focusing on intertemporal optimization in timber management (e.g., Berck 1979). This is accomplished by linking the anticipated effects of production on prices through time, recognizing that increasing harvests in one period can increase scarcity in subsequent periods. Accordingly, these models must explicitly account for the age distribution of the existing forest and its influence over production possibilities in the short run, as well as on the evolution of the age distribution through time. Furthermore, the connection between prices and quantities and therefore the market clearing mechanism must be specified.

The market problem can be solved using an optimization method that derives from Samuelson's (1952) finding that the competitive market solution occurs where the sum of consumer and producer surpluses is maximized. So, given a demand function for Y

$$p = \alpha + \beta Y \qquad 8.11$$

and an aggregate supply function

$$P = g^{-1}(Y) \tag{8.12}$$

Samuelson's intertemporal objective function is a simple quadratic function of Y:

$$Z = \sum_{i=1}^{T} (\alpha_i - \beta_i Y_i)Y_i - c(Y_i)(1+r)^{-i} + M_{T+1}(1+r)^{-(T+1)} \tag{8.13}$$

where i indexes time and M_{T+1} is a terminal value assigned to standing inventory at the end of the planning period (comparable to the bareland value in the Faustmann stand-level model). With information on the biological production functions, cost functions (c(y)), and the demand relationships (which now vary by time period), it is possible to solve 8.13 by maximizing Z with respect to harvests (Y).

This technique allows a detailed specification of timber inventories and other technical inputs. In this way it is similar to the engineering approaches. It departs from a purely normative assessment by incorporating econometric demand models in a market-simulating objective function. This specificity allows the direct analysis of a wide variety of questions about optimal investment levels and paths under varying conditions for various classes of ownerships. Another important aspect of this modeling approach is that, unlike econometric models, it provides a framework for simulating production in new policy environments and for unprecedented changes in environmental factors (e.g., climate change).

Gilless and Buongiorno (1987) have applied the methodology to U.S. pulp and paper industries. Sallnas and Eriksson (1989) provide an interesting approach that explicitly builds the market solution from the set of solutions to individual stand-level problems using a decomposition technique. They also allow for noise, or departure from the technically optimal solutions, for individual forest categories using an entropy constraint. Perhaps the most extensive application of the mathematical programming approach is found in a model of the U. S. rural land-based sectors called the Forest and Agricultural Sector Optimization Model (FASOM) (Adams et al. 1996) that focuses on the land use interface between agriculture and timber production. All of these models are constructed as static simulations, solving the problem on a period-by-period basis. It is also possible to approach the problem using dynamic optimization techniques such as optimal control or dynamic programming. Sedjo and Lyon (1990) provide an optimal control analysis of global timber markets. Sohngen and Sedjo (1998) compare and contrast the performance of the two different approaches.

While these models hold great advantage for generating hypotheses, evaluating nonmarginal changes, and making detailed long-run forecasts, normative models have no role in testing hypotheses regarding supply behavior. They are also highly sensitive to specification error in defining the behavior of forest managers. Positive timber supply models provide an alternative approach that can address these issues.

2.2 Positive Approaches

The structure of a statistical model of economic behavior is generally derived from the economic theory of rational behavior and then estimated using historical observations of production and consumption decisions. These models offer tools for testing economic hypotheses and have been applied in a wide variety of forms to timber markets. Statistical models of timber supply also define the core of many forecasting models in use today.

2.2.1 Individual Choice Models

One body of timber supply models is developed from observations on individual harvesting decisions. These individual choice models examine directly the implied marginal conditions between harvesting and delaying harvest on a particular stand for a particular owner (e.g., equation 8.3). Studies constructed at this level generally assume that the manager maximizes utility. Accordingly, positive harvest choice models are estimated using discrete choice methods (e.g., logit and probit models) fit to cross-sectional observations of harvest and delay choices and landowner and forest quality characteristics (see Binkley 198 1 and Dennis 1990).

By framing these decisions within a household production problem, these models can recognize tradeoffs between forestry and other household consumption decisions and between timber products (which may be sold to provide income and wealth) and other services (e.g., amenities) from forests that may be consumed by the household. The earlier empirical applications of the household production logic do not, however, explicitly model the nontimber outputs. Chapter 14 explicitly estimates harvesting and amenity choices. Studies that employ the household production framework provide insights into provision of wood products from a forested landscape with variable forest ownership characteristics and variable forest conditions. They are therefore useful for inferring the choice of variables and form of aggregate supply models.

Recent research has begun to explore the derivation of timber supply directly from these individual choice models. The conceptual bridge between individual and aggregate response is an estimate of how much of the inventory is represented by the observed individual. Hardie and Parks (1991) developed this bridge in their study of forest regeneration, using an area-based sampling frame of forest inventories conducted by the USDA Forest Service. This innovation allows aggregate behavioral responses to be built up directly from the individual survey plots. Prestemon and Wear (2000) applied this approach to define the aggregate softwood supply from the Coastal Plain of North Carolina. In effect, they directly applied the aggregation shown in equation 8.4 but with $\boldsymbol{H}$ representing harvest probabilities (shares) rather than binary choices. While promising for small areas, insights into supply may ultimately be limited by the lack of social data associated with owners of the plots.

2.2.2 Aggregate Supply Models

Aggregate timber supply models have also been developed from aggregate production models. Nearly all aggregate timber market models specify the same form for timber supply. Supply is modelled as a function of price (p) and standing forest inventory (I):

$$S = g(p; I, Z) \qquad 8.14$$

where S is timber supply and g is a function which is generally consistent with equation 8.10. This model derives implicitly from a forest production function, where I represents the accumulated capital inputs to forestry (i.e., the timber inventory, which results from time, effort, land quality, and possibly other capital inputs). Z is a vector of other supply shifters that may or may not be included in the supply model. Timber supply should be positively related to I and positively related to price. Because of price endogeneity, supply is usually jointly estimated with demand (i.e., variables influencing demand are needed to identify the supply equation). They are typically estimated using simultaneous equation techniques with time series data (Adams and Haynes 1980, Daniels and Hyde 1986, Newman 1987).

While these supply formulations have proved very useful for market analysis, they are not always explicitly tractable to theories of production behavior (Binkley 1987, Wear 1991). For example, these models cannot distinguish the effects of various structures of forest capital that might be represented by the aggregate quantity of timber inventory. When the age distribution and species composition of the forest capital is relatively constant over time, this may not be a problem. However, the misspecification may be serious when these qualities vary substantially (i.e., when simulated over long time periods).

Recent research into empirical aggregate supply models focuses on incorporating more inventory detail or explicitly deriving supply equations. Pattanayak et al. (2002) incorporate age distribution information in an aggregate supply model. Newman and Wear (1993) explicitly derive timber supply equations for the Coastal Plain of the southeastern United States from an aggregate short-run profit function directly comparable to equation 8.10. The model was estimated using cross-sectional observations of output, price, cost, and inventory variables. Yin and Newman (1997) apply a dynamic profit function approach.

2.3 Timber Supply: An Empirical Analysis

The southeastern United States is arguably the most important and the most active timber market in the world. Here, forest investment and harvesting have shifted timber production from an extractive to an agricultural endeavor. Timber harvests have increased steadily since the 1950s as forest inventories accumulated on lands previously dedicated to the production of cotton and other row crops. In 1997 the South contributed 58% of the wood products produced in the United States (Powell et al. 1993). Forest products industries have shifted their processing capital to the South from other regions, and forest production is an important part of many rural economies. In this section we develop a model of southern timber markets using historical time series data. The intent of the analysis is to illustrate some of the concepts developed in the theory section.

2.3.1 Defining Timber Supply

To develop an equation for timber supply, we construct the dual to the production technology described in equation 8.7:

$$\pi^{SR} = h(p, w; Z, t) \qquad 8.15$$

where p is a vector of output prices, w is a vector input prices, Z is the vector of quasi-fixed inputs to production, and t indexes profit consistent with the dating of technology in equation 8.7. In our production model we have forest capital inputs that are unlikely to be optimally adjusted in the short run (i.e., within the annual time step of the data used for this analysis), so assume that these should be classified as quasi-fixed inputs (i.e., there are no elements of w in equation 8.16. The supply of an output is derived from the profit function using Hotelling's lemma:

$$S_i = \frac{\delta \pi^{SR}}{\delta p_i} = g_i(p; Z, t) \qquad 8.16$$

so that the righthand side includes output prices (p) quasi-fixed input quantities *(z)*, and a time index *(t)*. We apply a quadratic profit function to the case with two variable outputs (sawtimber Y_s and pulpwood Y_p), two quasi-fixed inputs (natural forests Z_n and planted forests Z_a), and a quasi-fixed output (forest growth Z_g):

$$\pi^{SR} = a_0 + a_t t + \sum_i a_i p_i + \sum_j a_j Z_j + \frac{1}{2}\sum_i \sum_k b_{ik} p_i p_k + \frac{1}{2}\sum_j \sum_l b_{jl} Z_j Z_l + \sum_i \sum_j b_{ij} p_i Z_j + \sum_i c_i t p_i \qquad 8.17$$

Summations of *i* and *k* are over *s* and ***p***, and summations ofj and I are over n_L a, and g. The supply equations are therefore given by Hotelling's lemma as follows:

$$S_S = \frac{\delta \pi^{SR}}{\delta p_s} = a_s + b_{ss} p_s + b_{sp} p_p + b_{sn} Z_n + b_{sa} Z_a + b_{sg} Z_g + c_s t$$

$$S_P = \frac{\delta \pi^{SR}}{\delta p_p} = a_p + b_{pp} p_p + b_{ps} p_s + b_{pn} Z_n + b_{pa} Z_a + b_{pg} Z_g + c_p t$$

8.18

The forest quantity variables are measured as capital indices that require weighting each age/vintage class of forest area by its implied rental price using methods outlined in Wear (1994). These define a Tomqvist index of forest capital similar to indices of capital built from stocks of buildings, machinery, and other long-lived capital assets used in manufacturing (see generally, Caves et al. 1982).

2.3.2 Estimating the Supply Equations

We estimate these supply equations using annual observations on dependent and independent variables for the period 1965 to 1994. Forest capital measures are specified as described above. Timber quantities are estimated from output of final goods (e.g., lumber) using technical conversion factors. Prices of timber are indexed by softwood sawlog and softwood pulpwood prices reported by the state of Louisiana.

Price of timber products is endogenous to the sector, so we need additional information to identify the supply equations. This is accomplished by specifying demand equations for the two products. Following Newman (1987), we specify demand as follows:

$$D_i = g_i\left(p, p_{fi}, w_i, Y_{i,t-1}, t\right) \quad 8.19$$

where p_{fi} are the final product prices for the two sectors (final goods prices are defined as sector-specific producer price indices for lumber and wood products and paper and allied products sectors reported by the Bureau of Economic Analysis). Lagged production of i is represented by $Y_{i,t-1}$ and w_i is the wage rate for labor in the specified sector. For the pulpwood demand equation, we also include as an explanatory variable the quantity of residues from solidwood sectors used in paper production. This material has grown as an important substitute for pulpwood over the estimation period. Equation 8.19 is therefore consistent with derived demand using the profit function for the respective wood-using sector.

To address price endogeneity and the joint presence of autocorrelation and a lagged endogenous variable on the righthand side, we apply a three-stage least-squares estimator to the system of equations defined by 8.18 and 8.19. The initial Durbin-Watson and Durbin's h statistics indicated that autocorrelation corrections for the supplies of sawtimber and pulpwood were necessary. In addition, we impose symmetry on the profit function by requiring b_{ps} = b,. Note that the time trend was dropped from the estimation of the supply equations. Estimation results are shown in table 8.1.

Of 25 estimated coefficients, 18 are significant at the 10% level. All significant price/quantity coefficients have the expected signs: positive price coefficient for sawtimber supply and negative coefficients for both pulpwood and sawtimber demands. Evaluation of the coefficients for the capital measures indicates that pulpwood is responsive to planted capital but not to natural capital. Sawtimber supply is significantly responsive to both forms of capital. Sawtimber supply elasticities with respect to these measures of capital indicate that supply is much more responsive to natural capital (78.46) versus planted capital (0.059), consistent with expectations.

2.4 Contemporary Research Issues

The appropriate approach to modeling timber supply depends on the objectives of the analysis. Because they model production in a mechanistic fashion, engineering approaches, especially those driven by a dynamic optimization framework, hold advantage for analyses of the long-run supply

Table 8. I. Parameter estimates for the equation system defining pulpwood and sawtimber markets in the U.S. South

Parameter	Coefficient estimate	Approx. std.err.	T-ratio	Prob. > |T|
Pulpwood supply				
Intercept	954.21 1	1552.9	0.61	0.540
Price (pulpwood)	-1.253	17.819	-0.07	0.944
Price (sawtimber)	41.995	23.177	1.81	0.484
Planted forest capital	0.378	0.535	0.71	0.079 *
Natural forest capital	-87.054	1631.8	-0.05	0.958
Growth	0.143	0.0434	3.29	0.002 **
Adjusted R^2 = .93				
Pulpwood demand				
Intercept	-881.388	241.6	-3.65	0.001 **
Quantity (pulpwood)	-0.007	0.002	-3.47	0.001 **
Price (paper)	-0.123	0.045	-2.73	0.010 **
Residues	0.011	0.002	-6.72	0.000 **
Lagged pulpwood	0.002	0.002	1.29	0.205
Wages (paper)	1.552	0.560	2.77	0.009 **
Time trend	0.461	0.124	3.70	0.001 **
Adjusted R^2 = .63				
Sawtimber supply				
Intercept	-5374.75	2087.9	-2.57	0.015 **
Price (sawtimber)	1.374	0.774	1.78	0.085 *
Price (pulpwood)	41.995	23.177	0.71	0.484
Planted forest capital	100.276	28.875	3.47	0.001 **
Natural forest capital	6454.966	2057.7	3.14	0.004 **
Growth	-0.052	0.063	-0.83	0.41 1
Adjusted R^2 = .63				
Sawtimber demand				
Intercept	8959.024	2343.2	3.82	0.001 **
Quantity (sawtimber)	-0.282	0.0580	-4.85	0.000 **
Price (lumber)	2.737	0.3427	7.99	0.000 **
Lagged sawtimber	0.170	0.0532	3.19	0.003 **
Wages (lumber)	47.204	12.4658	3.79	0.001 **
Time trend	-4.619	1.2202	-3.79	0.001 **
Adjusted R^2 = .9 1				

*= significance at the 5% level

** = significant at the 1 % level

and structural changes in forest production (e.g., related to climate change). However, engineering approaches are susceptible to specification error and, because they are not fit to observations, may not be well suited for short- and medium-run analysis of market dynamics and policy effects.

In contrast, positive econometric models of supply are calibrated to observed producer behavior and provide a mechanism for testing various hypotheses regarding behavior and impacts. However, econometric models are not without potential specification problems. While individual choice models have a high degree of specificity regarding the structure of supply, aggregate models of supply often are based on *ad* hoc aggregations of timber capital. The theory discussed above suggests that the structure as well as the amount of forest capital should have a bearing on timber supply estimates.

Ongoing research focuses on the explicit aggregation of forest capital in timber supply models. One approach is to conduct modeling at finer scales, even at the level of the individual, and then aggregate the outcomes to simulate supply responses (e.g., Prestemon and Wear 2000). Another approach is to expand aggregate timber supply models to include additional information on the structure of timber inventory on the righthand side of the supply equation (e.g., Pattanayak et al. 2002). This can be accomplished by including additional variables—e.g., by expanding the vector of inventory attribute variables, Z, in equation 8.16—or by aggregating inventory in a way that is consistent with capital theory-i.e., consistent with the contribution of each component of the capital stock to production (as developed in the example in this chapter). This is an attempt to make the inventory shifter a measure of capital rather than purely a biological factor. One promising avenue of research is hybridizing normative and positive supply analyses. This approach allows empirical findings to inform long-run timber market projections.

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